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Forecasting Research

Forecasting Research Division
Technical Report No. 101

Surface ship position errors and detection algorithms

by

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June 1994

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N Bruce Ingleby

1. Introduction

The operational numerical weather prediction (NWP) system uses surface ship observations extracted from the Synoptic Data Bank (SDB). SDB software applies several checks to the observations, including a check for ships at land positions, and a movement check, in which the position is compared with an estimate derived from the position six hours earlier, and the reported speed and direction then. Within the automatic quality control applied for NWP purposes, ships with an SDB land or movement flags were given a Probability of Gross Error in position of 0.9 or 0.75 respectively. On 5 October 1993 this was changed so that ships with an SDB land flag are automatically rejected, and from 4 January 1994 ships with an SDB movement flag are given a Probability of Gross Error in position of 0.9. The investigation that lead to these changes was extended and forms the basis of this report.

SDB land and movement flags for 5-8 October 1993 were examined subjectively, using an interactive graphical display. Results from a different movement check were also compared. TEMPSHIPS and BATHYS (radiosonde and bathythermograph reports from ships) are also subject to position errors, unfortunately they are not subject to SDB position checks at present, neither are DRIFTERS (drifting buoys). These different observation types are discussed briefly.

Surface ship data is used within the Meteorological Office in the following applications:

atmospheric analysis for NWP,
Sea Surface Temperature (SST) analysis for NWP,
analysis for ocean forecasting (under development),
SST analysis for climate research.

The NWP applications are real-time, involving the latest ship observations. In this case it is not possible to check the position by interpolation from positions before and afterwards, a very useful check that is available in delayed-mode applications.

2. Ship position errors

Initially a list of SDB flagged positions from the operational NWP system was obtained for 5-8 October 1993 inclusive. These observations are then archived in the Observation Processing Database (OPD), unfortunately without storing the SDB position flags. Observations (taken from the OPD) for the first eleven days of October 1993 were examined using an interactive graphical display on a workstation, to decide subjectively if the flags were correct or not. Later a microfiche listing from an alternative track check (see

section 5 for details) was obtained, covering the first ten days of October 1993, and flagged and suspect positions were examined subjectively in the same way. Sections 4 and 5 discuss the efficiency of the two different algorithms in detecting position errors, this section will discuss the errors themselves.

Appendix A lists observations in the four day period with position errors. There were 8552 surface ship observations in the OPD in the four day period, and 115 of these are listed in Appendix A (there are an additional four observations listed that were not in the OPD). This gives an error rate of 1.34%, the true figure is estimated at about 1.5% as it is very likely that a few errors have escaped detection. Ingleby (1993) found that about 0.5% of TEMPSHIPs in an eight month sample had position errors. For cases where the TEMPSHIP and surface ship positions disagreed there were about two and a half times as many surface ship position errors. This leads to a similar estimate of surface ship position error frequency, within sampling limitations. Cross checks between TEMPSHIPS and surface ships would help as part of an overall position checking system.

Appendix A is in alphabetical order by callsign, the reported latitude and longitude are given, with an X after the incorrect figure. An attempt was made to subjectively determine the correct position, by reference to other observations in the sequence and where possible slightly altering the reported position. There are almost certainly a few errors among these subjectively determined 'correct' positions, however the overall impression of dominant error types should be reliable. Table 1 summarises these error types.

No	code	description
44	d	single digit error
20	td	transposed digits
16	q	quadrant error ie N/S, E/W wrong (5 were near the date line)
9	..Z pos	time error
3	dp	decimal point in wrong place
3	teen	eg 40 instead of 14
1	tll	transposed latitude and longitude
23	?	other errors
119		TOTAL

Table 1. The number of errors in each category, the codes used in the last column of Appendix A and a brief description of the error type.

Of the errors 44 affected latitude only, 54 longitude only, 15 latitude and longitude and 6 were indeterminate (callsign SHIP over land). One reason for the larger number of longitude errors, is that when ships cross the dateline the operators sometimes forget to use a different quadrant indicator (affected 5 reports). Of the 119 errors 12 were small: 2° or less.

3. Surface ship extraction

It was noticed that the alternative list from M Jackson includes ships at non-synoptic times, whereas the global assimilation only contains ships at 00, 06, 12 and 18 GMT. Some ships (including GACA, the UK weather ship) report hourly, and some report three-hourly; it seems likely that the ships making extra reports are more dedicated, and will produce good quality reports on the whole. A few ships report at 05, 11, 17 and 23 GMT.

The NWP system was not assimilating potentially useful data by only extracting ships at the main synoptic hours. For drifting buoys up to one an hour is used, with surplus reports being 'thinned'. On 7 June 1994 there was a change to extract and assimilate all surface ship data within the assimilation window. As the ships are not likely to report more frequently than once an hour there is no need to thin them (except for duplicate checks).

4. SDB position checks

a. Movement check

Two separate checks are applied, a land-sea check, and a check for excessive movement since the report six-hours earlier (SDB, 1990). Table 2 gives a breakdown of the SDB flags on the observations listed in Appendix A.

No	code	description
22	l	land (3 had CFO reject flags)
39	m	movement
26	nxt	movement flag on next observation
32	.	no flag
119		TOTAL

Table 2. The number of errors in each category, the codes used in the SDB column of Appendix A and a brief description of the flag type.

26 incorrect observations passed the SDB movement flag and caused the next (correct) observation reported to be rejected. In some cases there was no observation six-hours prior to the erroneous position, so it was accepted by default. The rather poor discrimination between whether the first or second observation is at fault is a serious deficiency in the algorithm. A minor improvement could be made by flagging both reports if the earlier one has not been validated; however, except for the update runs, this would be too late for the NWP suite. The obvious remedy is to consider a sequence of reports, not just two at a time.

Appendix B lists 9 further observations that were rejected wrongly by the movement check. Two of these were from ship "X" in the North Atlantic; the algorithm was confused by the existence of another ship "X" in the North Pacific. Trying to disentangle two tracks

with the same callsign would add significantly to the complexity of the algorithm, for a rather small improvement. No attempt is made to track check the callsign "SHIP", because there are often several different vessels using it. It is difficult to see why the other 7 observations in Appendix B were flagged by the movement check, except that there may have been additional late reports in the SDB that did not reach the NWP suite/OPD (presumably the case for NIDR).

Thus in the four day period the movement check correctly rejected 39 reports, but erroneously rejected 35 reports (the 26 'nxt' flags, plus the 9 in Appendix B), i.e. 47% of the flags were false alarms. Also 58 position errors were not detected (this is the sum of the 'nxt' and 'no flg' categories in table 2; the 'nxt' flags contribute both to the false alarms and to the misses). This is not a satisfactory performance. Most position errors should be detected by an automatic track check, with the exception of a few cases (such as duplicate callsigns, or corrupt callsigns) that cannot be handled well.

b. Land-sea check

A check is applied to discern whether any sea exists within the one-degree square occupied. With the check formulated in this way there should be no rejection of ships close to the coast, and a slight danger of accepting ship positions that are just inland. Of the erroneous observations in Appendix A, there are two (3EPB6 and WA6575) that are just inland that were not flagged by the land-sea check.

The location check rejected 46 reports that appeared to have correct positions. The majority of these, 38 reports, were from the St Lawrence and Mackenzie rivers in North America. It was decided that in view of the density of land surface observations in the region, these river reports are not essential, and the wind and temperature may be affected by local effects which cannot be represented in the global forecast model. To some extent the same arguments apply to ships in port of which there were 5 rejected (four from FNFD at Oran). With these minor exceptions, the land mask used seems satisfactory. It might be worth considering increasing the resolution of the land mask from the current 1° to 0.5°.

The location check rejects observations with a longitude of -180° (there were three in the period examined, from 4XGW, 9VOQ and KIRF), this is unnecessary and should be changed. The SDB land-sea check sets the 'location' flag, the movement check sets both the 'movement' flag and the 'location' flag to indicate that either of these could be in error. However this implies that if the movement check was failed, the user cannot tell if the land-sea check was also failed or not. This is unfortunate as the land-sea check is more reliable than the movement check. A simple improvement would be to disable the movement check if a land position has been detected. Alternatively the flag definitions could be changed slightly so that the movement check only set the movement flag.

5. An alternative track check

a. Method

In 1992, M Jackson of the climate research division set up his own surface ship track check, because of shortcomings in the SDB movement check. This is part of the quality control applied in the production of sea surface temperature analyses for climate use. The following is a condensed description of the method.

Ten days of ship positions are extracted and sorted by callsign and chronological order. For each callsign, each position is subjected to the following tests:

1) Recognition of speed pattern
   A - excessive speeds calculated from positions of two previous observations
   B - excessive speeds calculated from positions of two subsequent observations
   C - excessive speeds calculated from position of previous ob and subsequent ob.
2) Comparison with position calculated from previous position and reported speed and direction of travel.
3) Comparison of actual and reported direction of travel
4) Comparison of actual and reported speed of travel
5) Speed greater than 40 knots
6) More than 150 miles distant from position interpolated from previous and next observations

If an observation fails tests 1 and 6 and at least two of the other tests then it is marked as incorrect. The tests are repeated five times, each time excluding those observations which have previously been marked as incorrect.

b. Results

This algorithm was investigated as a possible prototype for a new, general purpose ship track check. It has the obvious advantage over the SDB movement check that a sequence of observations is used. In appendix A, the column marked J is

F flagged
s suspect (listed because at least one position from the ship was suspect)
. not listed

The following comments are based upon the full ten days data in the microfiche listing, some of which appears in Appendix A.

a) the check detects a significant number of errors that had passed the SDB checks. In general it was quite effective at detecting individual position errors in the interior of the sequence (although in a few cases an adjacent good report was also flagged, eg 9KKF, DIIU, GHJW, VROT).
b) there is no land check. Eg three reports from BKFS/ prior to 5 October had a quadrant error - the reports in North Africa were not flagged. A land/sea check is

applied in the SST analysis. However, a land check can provide useful information to a track check and should be incorporated.

c) the check does not detect errors in the first or last observation of a sequence (eg 3ELF9, UQYZ, VJD2607, VRIY, VTKW, UZNS, VDFP, WGZK), because test 6 cannot be completed without both a prior and subsequent report, and without test 6 the report cannot be flagged. The program could not be used for real-time applications without correcting this deficiency. The climate SST analysis uses reports from a five day period within the ten day dataset, so that for many ships the first and last reports in the sequence will be outside the analysis window.

d) multiple errors are not well handled. If there are adjacent errors, or errors separated by one correct observation then the algorithm may reject some of the good observations as well as the bad ones (eg CFD3659, DQEB, EWAK, KGJD, PGFU, SXVS, UTYE, UYLS, XX06, ZMQN). Occasionally it can be simply inconsistent as to which observations are retained and which rejected (eg V2LV). It is clear that multiple errors occur more often than if all errors were distributed at random: some ships are more error prone than others, and sometimes several reports have a consistent error (eg quadrant error).

e) poor handling of large gaps. Eg WZJF (previous report 3 days, 6 hours earlier), XYEJ (previous report 4 days earlier). It may be that too much weight is being put on the reported speed and direction of travel, when the vessel has been into port in the meantime.

In general the comments above give the impression that this algorithm flags too many observations. On average it rejects about 2.7% of reports, this is much higher than the error rate of about 1.5% estimated in section 2.

c. The way forward?

Some improvements could be made by changing details of implementation. It seems likely that the general over-flagging could be reduced, and that checking of the first and last observation in the sequence could be allowed. There is some redundancy in the tests applied, particularly between test 2 and 3/4. However, the most fundamental criticism is that applying a series of tests to individual reports does not ensure overall consistency, and has particular difficulty in coping with multiple errors.

It would be better to pose the question "what is the largest sub-set of consistent observations, based on the maximum speed of the vessel?". Reports over land could be eliminated in a preliminary step, and once the best track has been found inconsistent positions should be rejected, or possibly corrected. Neither track check examined has a test for different positions at the same time, there are six such 'duplicates' listed in Appendix A (marked dup), such a test would be implicit in an overall consistency check.

In many cases it would be useful to try to fit a straight line track to the observations, such track estimation would allow for position correction. Regression is an obvious

approach, but it is sensitive to outliers. This can be dealt with by initially overestimating the observation position error, rejecting obvious outliers then repeating, gradually reducing the error estimates. Alternatively a straight line could be calculated for different pairs of observations chosen at random, and then other observations consistent with that track added to the subset, the largest subset is then chosen (this is essentially the 'consensus averaging' method of Fischler and Bolles (1981)). The curvature (in latitude-longitude coordinates) caused by ships using great circle tracks could be alleviated by first transforming to a local frame of reference. Ocean weather ships, research vessels and trawlers sometimes steer zig-zag patterns. These are often at low speed and so differences from the best track would be within observation error. At moderate speeds changes in direction would cause problems, this could be dealt with by assigning larger position errors to older observations, or by ignoring older observations completely if the fitting algorithm is not converging well.

As to the length of sequence to be used in any track check, ten days seems somewhat longer than necessary (not harmful, but increasing storage and processing costs) - about half of that would suffice in most cases. Reported speed and direction could be incorporated into an overall consistency check, but it is our impression that the extra improvement gained would not be large: the subjective checking in this report used only the observation positions.

6. Drifting buoys

A modification was made to the surface quality control to print a message if a particular drifting buoy moves more than 100 km during the six-hour analysis window. This was run on the data sets for each analysis over the four days used for ship track checking above (5-8 October 1993). These contained a total of 13395 drifting buoy observations. Briefly the results were:

a) Drifter 62711 was flagged by the check for many of the analysis periods. There were in fact two different drifters in the North Atlantic using the same identifier!

b) Drifters 55520 and 55513 were flagged for 4 and 5 analysis periods respectively. On inspection of the tracks one of them had travelled from New Zealand to Australia, the other traversed the East coast of Australia. Some drifting buoy instrument packages have been mounted on yachts, this may be the case for these two.

c) There were 10 errors from different drifters. The errors varied between just over 1 degree (latitude or longitude) to about 40 degrees. Six of these reports contained no atmospheric data, two more contained wind but not pressure (at present only drifter pressure observations are assimilated). The two which reported pressure (44775 and 62805) were both in the North Atlantic, and both had quite small location errors. There was one other error in the North Atlantic (from 13579) of about 30° longitude. The other 7 errors were from buoys in the Pacific.

d) Errors that are isolated in time may escape detection by a check working independently on six-hour periods. A quick visual examination noted errors for three other drifters in the Pacific (not reporting pressure data and only one reporting wind). On investigation there are many buoys in the tropical Pacific as part of the TOGA-COARE

program: some are moored in North-South chains and report wind but not pressure, the true drifting buoys are used as tracers of the current and unfortunately do not measure either wind or pressure.

Table 3 summarises the frequency of pressure and location errors of drifting buoys in the North Atlantic taken from Ellis (1994) and previous reports in the same series. The larger number of position errors between July and September 1993 was attributed to problems at two specific Local User Terminals (receiving stations). This and the limited study above suggest that position errors in drifting buoys are quite rare, perhaps affecting 0.1% of observations or less, possibly with regional variations. (Just after writing this, on 13/14 June 1994 many drifting buoy positions were wrong following a coding change at a major processing centre.)

Quarter	Number of pressure errors	Number of location errors	Buoy hours
Apr-Jun 1993	273	9	31,378
Jul-Sep 1993	110	45	27,935
Oct-Dec 1993	116	11	36,480
Jan-Mar 1994	113	4	27,105

Table 3. Numbers of errors from drifting buoys in the North Atlantic taken from reports by Ellis. Several observations from the same drifting buoy within the same hour are counted as only one buoy-hour.

Most drifting buoys transmit messages continually, they are relayed by system Argos via a NOAA operational polar orbiting satellite when one passes nearby (several messages, a few minutes apart can be relayed in one satellite pass). If only one satellite pass is available then there is a 5% chance of position aliasing (symmetrical about the satellite sub-track), and the DRIFTER code now in use contains a flag, Q_L, to warn of this (WMO Manual on Codes). It would be desirable to determine how useful this flag is in detecting position errors, but this was not done in the present study, and it appears that only a minority of DRIFTER reports contain this flag at present.

At present there is no SDB check for drifting buoy position errors. The track check described in section 5 checks drifting buoys in the same way as ships. They are allocated a default maximum speed of 25 knots. This over-generous estimate in effect takes account of minor positional variations quite close together in time. It would be better to allow separately for errors in reported positions and speeds. However, because of the relative infrequency of drifting buoy position errors priority should be given to the detection of surface ship and TEMPSHIP position errors.

6. Summary

Based on subjective evaluation of a four day period it is estimated that about 1.5% of surface ship reports have position errors. Some ships are more error prone than others. Errors in a single digit account for over 35% of the total, followed by transposed digits, quadrant errors and positions for the wrong time.

It was realised that only reports for the main reporting hours were being extracted for NWP. There has been a change to extract all surface ship data.

The SDB land-sea check is generally satisfactory, although rejection of observations at -180° and the overwriting of the land flag by the movement check should be addressed. The SDB movement check only tests against the position six hours earlier: almost half of these flags are wrong, mainly because the previous position was wrong, even more position errors go undetected. **The SDB movement check is unsatisfactory and should be replaced by a sequence test using several days' reports.**

An alternative movement check was also investigated, this uses ten days of positions. This has a better detection rate, at the cost of rejecting too many observations. Various specific problems were noted including a lack of flags on the first and last reports in the sequence, and inconsistencies in the decisions made, due to the way one observation at a time is tested. It was suggested that a check which finds the maximal consistent subset of observations would be better, perhaps including an attempt to model the track.

Drifting buoys are subject to occasional position errors, affecting perhaps 0.1% of observations. There was one instance of a duplicate identifier, and examples of moored buoys and ships reporting as drifting buoys.

Acknowledgement: Thanks are due to M Jackson for providing the description of his algorithm, and the listing for the period investigated.

7. References

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Appendix A. Surface ship position errors 5-8 October 1993

DDHH	Callsign	Lat reported	Long reported	Lat correct	Long correct		SDB	J		error type
8 06Z	0600Z	14.1	43.2X	14.1	42.3		l	.		td
7 18Z	3EAY7	40.0	178.3X	40.0	-178.3		nxt	F		q
8 18Z	3EDO4	42.7	-70.2X	42.7	-10.2		m	F		d
8 06Z	3EFW8	36.6X	-122.5X	35.0	-121.4			F		12Z pos
8 12Z	3EFW8	35.0X	-121.4X	36.6	-122.5		nxt	s		06Z pos
5 12Z	3ELF9	40.3	-21.3X	40.3	-68.2		.	s		?
8 12Z	3EPB6	43.7	144.4X	43.7	147.0		.	F	lnd?	?
7 06Z	4XII	52.2	167.8X	suspect			.	s		00Z long
7 12Z	9KKF	-27.9	119.0X	-27.9	11.9		m	F	lnd	dp
5 12Z	BKFS/	-11.6	-26.4X	-11.6	-0.4		.	F	1/day	?
6 12Z	CFD3659	46.3X	-59.4	64.3	-59.4		m	F		td
6 18Z	CFD3659	46.2X	-59.6	64.2	-59.6		nxt	F		td
5 12Z	DDRC	66.0X	-20.4X	20.4	-66.0		nxt	F		tll
6 18Z	DHCU	20.8X	-69.2	21.8	-69.2		.	s	dup	d
5 00Z	DIIU	13.4	-74.6X	14.2	-79.6		m	F	dup	d
5 00Z	EKLW	40.3X	136.0	43.0	136.0		nxt	F		td
7 18Z	ELAJ6	36.5	-24.7X	36.5	-42.7		.	F		td
7 00Z	ELBG9	14.6	124.4X	14.6	128.4		m	F		d
5 18Z	ELFV2	42.9	174.9X	42.9	-174.9		nxt	F		q
5 12Z	ELGG	34.9X	-19.3X	-34.9	19.3		m	F		q
7 12Z	ELQA8	14.4	-12.7X	14.4	-22.7		m	F	lnd	d
6 00Z	EWWV	30.0X	159.8	53.0	159.8		.	F		?
8 12Z	FNVP	40.7X	-7.1	47.0	-7.1		c	F	lnd	td
5 18Z	FVJD	48.1X	-1.4	46.1	-1.4		c	s	lnd	d
6 12Z	GHJW	24.2X	-34.1X	42.2	-38.1		.	F		td
7 12Z	GJMP	55.7X	-5.9X	57.3	-6.5	?	.	s	stat	?
8 06Z	GOYC	39.8	-99.4X	39.8	-9.4		l	F		d
5 18Z	GOYE	11.9	5.9X	11.9	59.0	?	l	F		dp
5 18Z	GQHC	30.7	-40.5X	30.7	-14.5		.	F		teen
8 00Z	GRZE	13.6	14.4X	13.6	41.4		l	F		td
8 12Z	GXOZ	-4.1X	-32.6X	-5.7	-33.6		m	s		18Z pos?
6 00Z	J8FO	15.5X	-9.5	45.5	-9.5		m	F	lnd	d
7 00Z	JBCN	40.0	177.9X	40.0	-177.9		nxt	F		q
6 06Z	JKRV	18.1	126.4X	18.1	128.4		nxt	s		d
6 12Z	KFDZ	37.0	-57.8X	37.0	-51.8		.	F		d
7 00Z	KGJD	50.6	165.6X	50.6	-165.6		.	F		q
5 00Z	KNJN	29.3	-111.6X	29.3	-116.1		l	.		td
5 00Z	LAOO4	59.0X	-60.4X	37.5	-59.0		m	F		?
7 12Z	MNNU8	25.1X	-17.3	23.4	-17.3		nxt	s		?
6 18Z	NAMW	36.3	11.9X	36.3	14.9		.	s		d
8 00Z	ODGI	-13.2X	112.0	-30.2	112.0		m	F		teen
8 18Z	PCUI	-0.9X	125.7	0.9	125.7		.	s		q
5 06Z	PEVR	38.8X	3.7X	38.6	4.5		.	s	dup	00Z ob?
5 00Z	PFNG	37.7	-61.2X	37.7	-16.2		m	F		td
5 18Z	PGCY	-34.4X	17.7X	12.0	48.0	?	m	F		?
6 12Z	PGDL	-4.4X	93.0	4.4	93.0		m	F		q
6 12Z	PGDR	6.0	97.9X	6.0	94.9		nxt	F		06Z pos?
6 00Z	PGDX	-9.0	30.5X	9.0	130.5		m	F	lnd	d

DDHH	Callsign	Lat reported	Long reported	Lat correct	Long correct	SDB	J		error type
5 06Z	PGEB	34.5X	143.7X	34.4	145.1	nxt	s		00Z pos?
7 06Z	PGFU	-35.1X	-34.1	35.1	-34.1	.	F		q
7 18Z	PGFU	-33.4X	-35.9	33.4	-35.9	nxt	F		q
5 00Z	PGHC	-35.9	179.0X	35.9	-179.0	nxt	s		q
6 06Z	PGQY	12.6X	-7.3	46.0	-8.5	m	F	lnd	?
8 12Z	PHVG	-31.3	-154.9X	-31.3	154.9	m	F		q
5 12Z	PJQI	15.3X	-1.5	50.3	-1.5	.	F	lnd	teen
7 18Z	PJYG	20.6	-72.5X	20.6	-74.5	m	s		d
6 00Z	REPORT	52.2X	-26.4	55.2	-26.4	m	F		d
6 18Z	SCIP	51.1	-35.5X	51.1	-34.5	.	s		d
5 06Z	SHIP	33.8?	6.7?			l			
6 18Z	SHIP	32.4?	44.1?			l			
8 00Z	SHIP	-16.8?	19.9?			l			
8 12Z	SHIP	3.8?	44.2?			l			
8 18Z	SHIP	5.0?	43.3?			l			
5 06Z	SXVS	7.6X	108.9	15.7	109.1	.	F	stat	?
5 18Z	SXVS	7.6X	108.9	15.7	109.1	.	F	stat	?
6 00Z	UEBT	45.8X	163.1	54.8	163.1	.	F		td
5 18Z	UEVG	13.2X	-39.8	31.2	-39.8	nxt	F	late	td
5 18Z	UHCC	5.1X	-30.6	-5.1	-30.6	.	F		q
5 18Z	UHUN	-32.3X	13.2	-22.3	13.2	nxt	F	late	d
7 12Z	UIBY	50.2	130.3X	50.2	-130.3	l	.		q
6 12Z	UJFY	-42.7	160.5X	-42.7	170.5	m	F		d
7 12Z	UKMG	52.8X	146.9	42.8	146.9	nxt	F		d
5 12Z	UKTV	78.3X	20.7	73.8	20.7	nxt	F		td
5 00Z	UPGQ	13.3	114.1X	13.3	111.1	.	F		d
8 06Z	UQYZ	23.0X	157.4X	22.2	156.1	.	s		12Z pos?
8 18Z	UQYZ	23.9	168.9X	23.9	158.9	.	s		d
5 00Z	UTYE	9.9X	-16.8X	13.5	-19.8	.	F		?
6 00Z	UTYE	18.5	-77.7X	18.5	-17.7	.	F		d
6 18Z	UUQI	59.3X	143.2	52.9	143.2	nxt	F	late	td
8 12Z	UYLS	24.4X	-59.1	26.6	-59.1	m	F		?
7 00Z	UYNM	50.0	163.4X	50.0	153.4	nxt	s		d
8 12Z	UZNS	47.5X	147.4X	47.1	146.2	.	s	dup	06Z pos
7 00Z	V2CJ	65.9X	-16.0	63.9	16.0	l	.		d
6 18Z	V2LV	13.5X	-55.2	6.5	-55.2	m	s		?
6 18Z	V2LV	13.5X	-55.2	6.5	-55.2	m	s		?
8 06Z	VA4786	44.3?	-79.5?	?	?	l	.		?
5 00Z	VCJM	47.4X	-83.2	44.7	-83.2 ?	l	.		td
8 12Z	VDFP	41.4X	-87.0	44.1	-87.0 ?	m	s		td
8 00Z	VOWN	61.5X	-73.5	62.5	-73.5	l	.		d
5 00Z	VPGT	36.3	18.5X	36.3	16.5	m	s		d
7 12Z	VRID	34.1X	16.3	36.1	16.3	nxt	s		d
8 00Z	VRIW	-74.7X	80.6	-34.7	80.6	m	F	lnd	d
8 00Z	VRIW	-74.7X	80.6	-34.7	80.6	m	F	lnd	d
7 18Z	VRIY	-14.2X	-79.5	14.2	-79.5	m	s		q
8 06Z	VRMH	9.8X	87.9	0.8	87.9	nxt	F		d
5 00Z	VRQY	47.5	-140.3X	47.5	-146.3	m	F		d
6 00Z	VRSM	2.0X	39.0	20.0	39.0	m	F	lnd	dp
5 00Z	VTKW	-4.2X	105.9	4.2	105.9	nxt	s		q

DDHH	Callsign	Lat reported	Long reported	Lat correct	Long correct	SDB	J		error type
7 12Z	VYNG	47.1	-81.7X	47.1	-85.7	m	s	lnd	d
7 18Z	WA6575	43.1	-82.9X	43.1	-86.9	.	F	lnd	d
5 06Z	WB4520	43.1	-83.3X	43.1	-86.3	m	F	lnd	d
6 00Z	WCGN	30.9X	-125.9	40.9	-125.8	nxt	F		d
5 12Z	WCOB	1.3X	59.4	10.3	59.4	m	.		td
7 00Z	WE7207	43.3	-87.1X	43.3	-82.1	m	s		d
5 06Z	WGXO	7.2	28.1X	7.2	82.1	l	F		td
5 06Z	WGZK	28.2	-84.4X	28.2	-88.4	.	s		d
7 18Z	WPFZ	38.2	-56.7X	38.2	-53.7	m	s		d
8 18Z	WPFZ	38.5	-26.4X	38.5	-62.0	.	F		td
8 06Z	WPVD	47.3X	-39.4	43.7	-39.4	m	F	dup	td
5 18Z	WRYC	53.9	-178.1X	53.9	178.1	m	s		q
8 18Z	WXVH	23.4	-50.2X	23.4	-57.6	m	.		?
7 18Z	WYP8657	48.0	-82.2X	48.0	-87.2 ?	l	F		d
8 00Z	WYZ3931	43.8X	-85.0	46.8	-85.0	l	F		d
6 18Z	XX06	12.7	-0.6X	12.7	-70.6	l	F		d
7 06Z	XX06	12.4	-90.6X	12.4	-70.6	m	F		d
4 18Z	XX50	58.1	18.0X	58.1	8.0	nxt	s		d
8 12Z	ZCAF8	25.6	-75.7X	25.6	-76.7	.	s		d
6 00Z	ZMGB	-37.6	178.4X	-39.6	178.4	nxt	s		d
5 12Z	ZTSG	-2.2X	-7.0X	-33.3	17.7	nxt	F	dup	?

Table A1. Day, hour, callsign, reported latitude and longitude, correct latitude and longitude and quality control information for ships with position errors. SDB flags: l - land, m - movement, nxt - next observation flagged by movement flag, c - CFO reject flag (SDB flags not stored). Flags from alternative movement check (column J): F flagged, s - suspect. Notes: lnd - land (noted for obs without an SDB land flag), dup - duplicate report (same time but different position), late - not in OPD, stat - stationary. For explanation of error types see section 4a, table 1.

Appendix B. Reports flagged erroneously by SDB movement check

DDHH	Callsign	Lat reported	Long reported		Lat previous	Long previous	notes
5 12Z	DCG2959D	47.5	-44.4	m	47.5	-44.5	both OK-trawler?
6 18Z	DCG2959D	45.4	-48.8	m	45.6	-47.4	both OK
5 18Z	DCGJYD	47.6	-52.7	m	47.3	-52.7	both OK-buoy?
6 06Z	GQHC	32.5	-13.5	m	32.3	-13.6	both OK
6 00Z	NIDR	27.3	-78.0	m	missing		ob OK?
5 12Z	TFEA	63.9	-30.4	m	63.9	-30.5	both OK
7 06Z	USZY	53.0	159.7	m	53.5	161.1	both OK
5 06Z	X	57.1	-20.0	m	57.5	-17.9	both OK, dup X
5 12Z	X	56.6	-22.2	m	57.1	-20.0	both OK, dup X

Table B1. Previous position (from the OPD) is not necessarily the previous position used by the SDB movement check.